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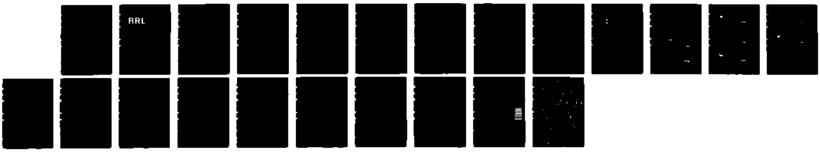

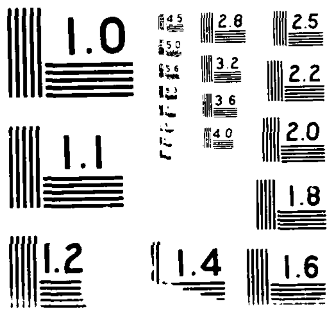
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TECHNICAL REPORT BRL-TR-2913

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STRUCTURE LIMITS FOR A 30-MM ANNULAR PISTON

CRIS WATSON

MAY 1988

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U.S. ARMY LABORATORY COMMAND

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The annular injection piston of the 30-mm regenerative liquid propellant gun was subjected to a stress analysis to determine if the existing design could be used in high performance firings. The piston was shown to fail under 558 MPa chamber pressure using finite-element stress analysis. This study concluded that the piston must be redesigned to reduce the unbalanced forces which exist across the thin shell portion of the piston wall before high performance firings with this fixture could be attempted.

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I. *INTRODUCTION*

General Electric Ordnance Systems Division (GEOSD) at Pittsfield, MA, under contract to the BRL, has designed and fabricated a 30-mm regenerative liquid propellant gun (RLPG) system. The fixture was installed at the BRL in July, 1984. The fixture is now being used to evaluate liquid propellants and study various features of the RLPG cycle.

To obtain a set of structural and performance limits for the 30-mm RLPG, a finite element analysis was undertaken on the most highly stressed component of the fixture, the annular injection piston. Initial and boundary conditions for the analysis were obtained from both pressure and piston travel records taken from actual firings and interior ballistic simulations.

The information obtained from the analysis will be used to determined if this 30-mm RLPG can be used in the high pressure liquid propellant gun firings. Chamber pressure may be as high as 700 MPa which, because of the differential area piston, may produce up to 1000 MPa in the liquid propellant reservoir.

II. REGENERATIVE LIQUID PROPELLANT GUN

Most studies of the liquid gun propulsion technology have been directed toward the bulk-loaded approach. While the bulk-loaded approach is simplier mechanically, the regenerative technique offers greater control over the ballistic cycle.

The regenerative liquid propellant gun cycle uses a differential area piston to pump liquid propellants into a combustion chamber. Figure 1 illustrates a simple regenerative piston concept that was studied extensively by GEOSD and others.[1,2] The propellant burns in the combustion chamber, sustaining the pressure which drives the piston. While the simple system shown in Figure 1 is adequate for performing various parametric studies, it is not acceptable for practical systems.

For practical systems, methods must be provided for rapid projectile, propellant, and igniter loading; confinement of the liquid propellant to the reservoir prior to ignition; possibly prepressurization of the liquid propellant to reduce the ignition risk from adiabatic compression of bubbles in the liquid propellant; and a capability for variable charge loading in the case of artillery applications. One approach for satisfying these requirements is a configuration which uses an annular piston similar to that shown in Figure 2.

The 30-mm RLPG at the BRL test facility uses an annular piston to inject a monopropellant into the chamber. The propellant enters the combustion chamber as an annular sheet, where it breaks up into droplets and combusts. The injection is controlled by tapers on the central control rod.

The constant diameter portion of the rod controls the maximum pressure. The charge length may be varied by changing the length of the constant diameter section.

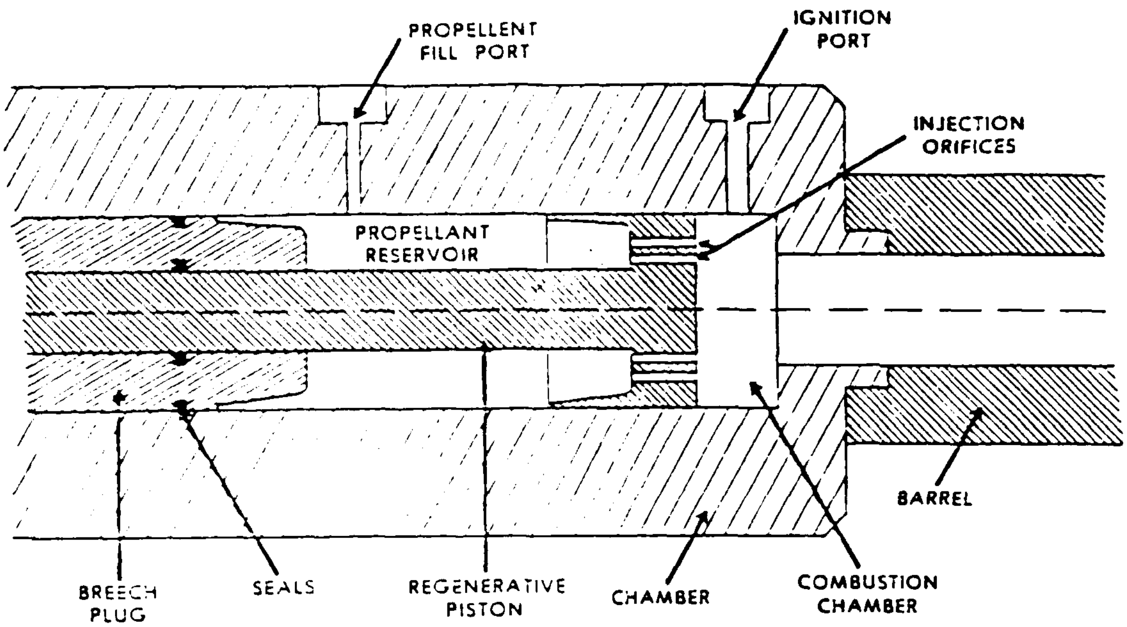

Figure 1. Basic Regenerative Liquid Propellant Gun (RLPG)

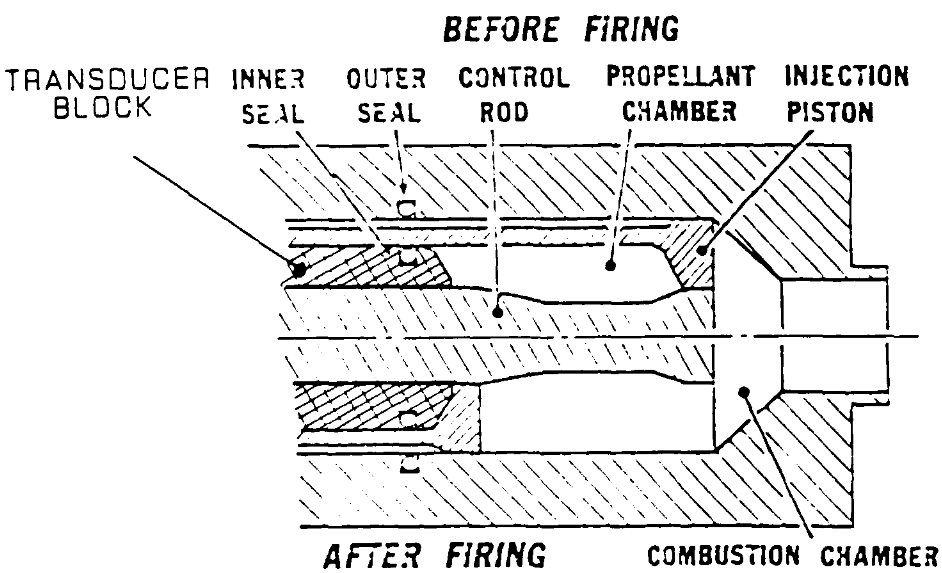

Figure 2. Annular Piston RLPG

The RLPG cycle starts with the transducer block forward, resting against the rear of the piston. The piston is supported by a spacer in the forward part of the combustion chamber. As the fill cycle begins, propellant is forced through a check valve in the rod and enters the liquid propellant reservoir. Ullage is removed through a port in the transducer block. Pressure in the reservoir forces the transducer block rearward until it encounters a stopping cone on the central rod. The system is then prepressurized to 7 MPa to reduce the chance of ignition due to adiabatic heating of the remaining ullage. The fixture is then ready to fire. A solid propellant igniter is used to initiate the cycle. As the pressure rises in the combustion chamber due to the igniter, the piston is forced back generating a gap between the piston and the rod. Propellant enters the combustion chamber through this gap where it breaks up and burns. The forward taper of the rod controls the start-up of the cycle. The system approaches a steady state condition as the pressure generated by the burning liquid propellant forces the piston over the constant diameter portion of the central rod. As the piston encounters the rear taper, the injection area decreases causing the liquid propellant pressure to increase, which in turn decelerates the piston. The piston stops when it contacts the face of the transducer block at the rear, ending the cycle.

III. STRESS ANALYSIS PROCEDURE

Stress data was generated using the SAAS-II finite element computer code.[3] Applied loads were taken from 30-mm RLPG firing data and appropriately scaled for this analysis. The loads are listed in Table 1. The scaled firing data represents pressures which would be encountered in the higher pressure operating regimes. A quasi-static, steady-state linear analysis was adequate for this problem because the period of mechanical vibration of the piston is an order of magnitude higher than the pressure pulse. Figure 3 shows the location of the static load placement and boundary conditions.

The piston was manufactured of PH13-8MO precipitation-hardened stainless steel hardened to a Rockwell C-scale of 38-42. A summary of the properties of the PH13-8MO stainless steel are given in Table 2.

TABLE 1. Loads Used in the Stress Analysis Calculations

Stress Analysis #	Combustion Chamber Pressure (MPa)	Liquid Reservoir Pressure (MPa)	Grease Pressure (MPa)
1	413	578	462
2	482	675	539
3	551	771	617
4	620	868	694
5	689	964	771
6	558	781	624

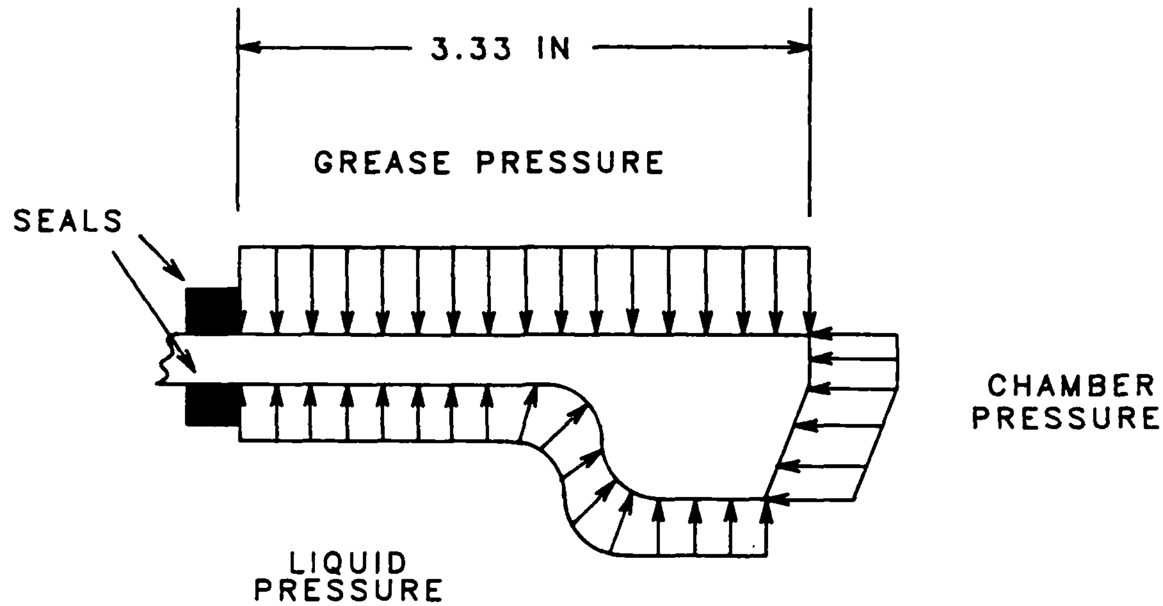

Figure 3. Static Pressure Loads and Boundary Conditions

TABLE 2. Material Properties of PH13-8MO Stainless Steel (4)

Modulus of Elasticity		= 205.8 GPa
Poisson's Ratio		= 0.28
Shear Modulus		= 79.9 GPa
Yield Stress	(0.2%)	= 1240 MPa

IV. RESULTS

The maximum effective stresses (von Mises criterion) in the piston are plotted in Figure 4. This plot represents the computed maximum effective stresses for six analyses using the scaled pressure data from Table 1. Figure 4 shows that the maximum effective stress exceeds the yield stress, 1240 MPa, when the chamber pressure exceeds 558 MPa.

Figures 5-11 shows effective, radial, axial, and hoop stress contours plotted graphically along the length of the piston. Figures 12 and 13 show the undeformed and deformed grid under 558 MPa chamber pressure. The piston fails at the thin walled section between the piston head and the seal location. Failure in this location results in increased clearance between the seal and piston and promotes leakage.

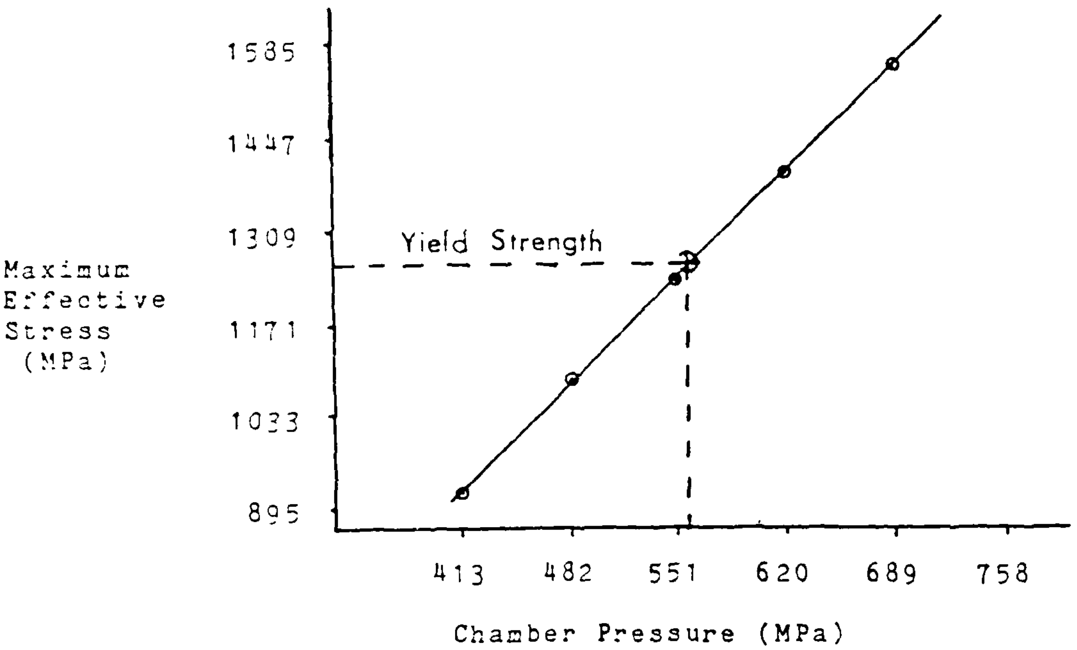

Figure 4. Maximum Effective Stress vs. Chamber Pressure.

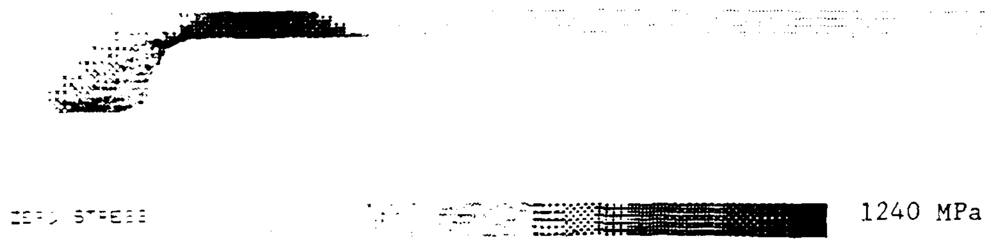

Figure 5. Effective Stress Contours at 558 MPa Chamber Pressure

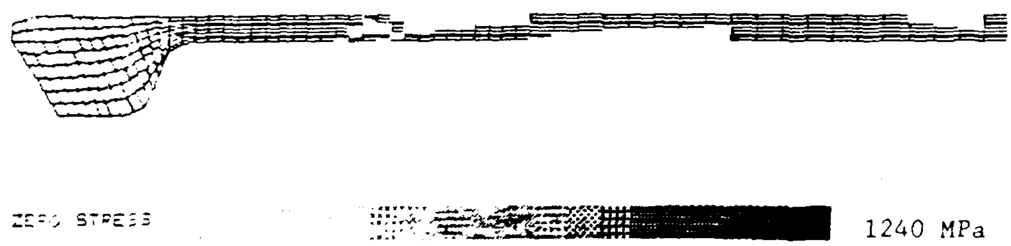

Figure 6. Radial Tension Stress Contours at 558 MPa Chamber Pressure

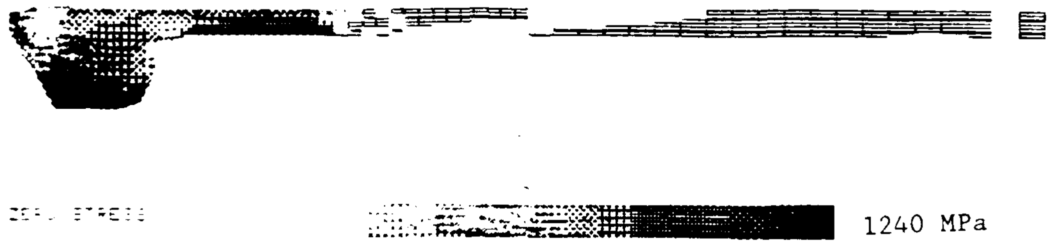

Figure 7. Radial Compression Stress Contours at 558 MPa Chamber Pressure

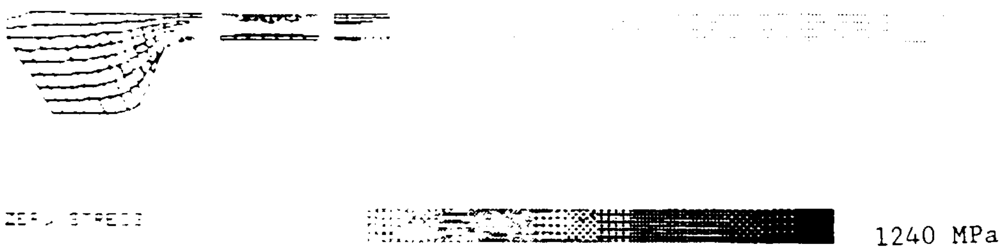

Figure 8. Axial Tension Stress Contours at 558 MPa Chamber Pressure

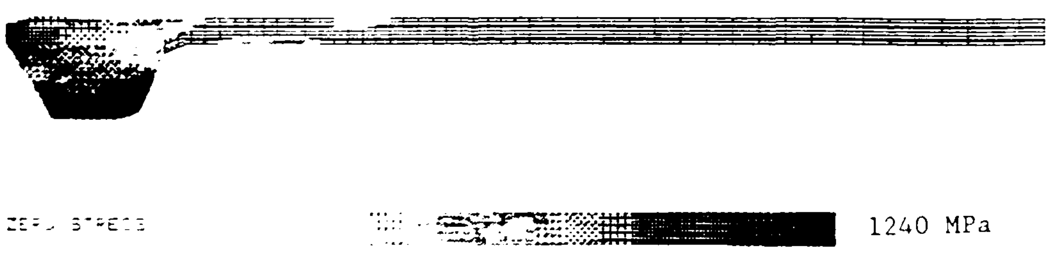

Figure 9 Axial Compression Stress Contours at 558 MPa Chamber Pressure

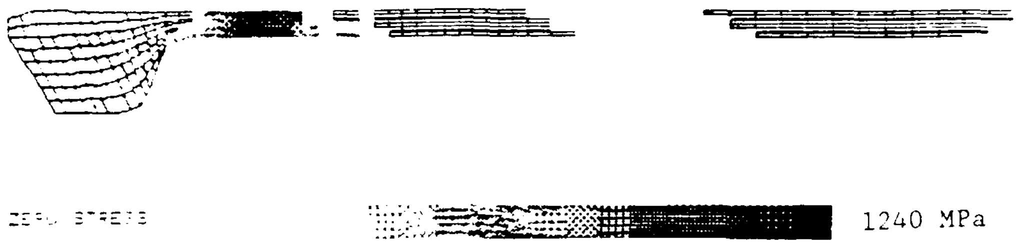

Figure 10. Hoop Tension Stress Contours at 558 MPa Chamber Pressure

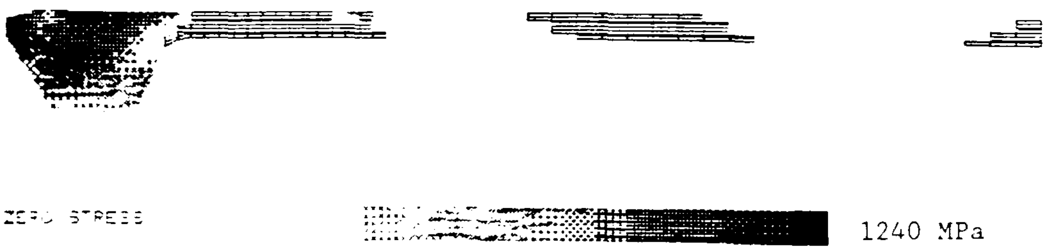

Figure 11. Hoop Compression Stress Contours at 558 MPa Chamber Pressure

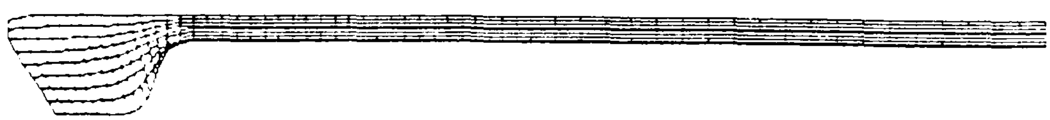

Figure 12. Undeformed Grid

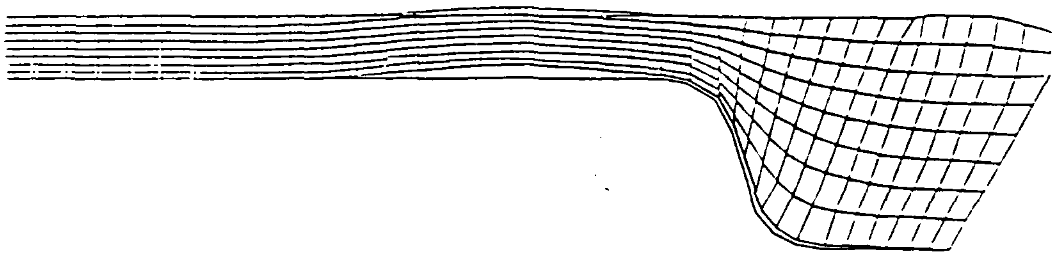

Figure 13. Deformed Grid (Enlarged 1.6x)

V. CONCLUSION

Results from the stress analysis show that the thin-walled section of the piston will undergo a permanent deformation when the chamber pressure is 558 MPa. The present piston, which was designed for lower operating pressures (350 MPa), is not suitable for a gun system where the chamber pressure exceeds 558 MPa and where unbalanced forces exist across the thin-walled section of the piston. A piston designed for higher operating pressures must reduce these unbalanced forces across the thin-walled section to work.

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